SP PHOTON DETECTION CONSORTIUM

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PD Consortium Management Table of Organization

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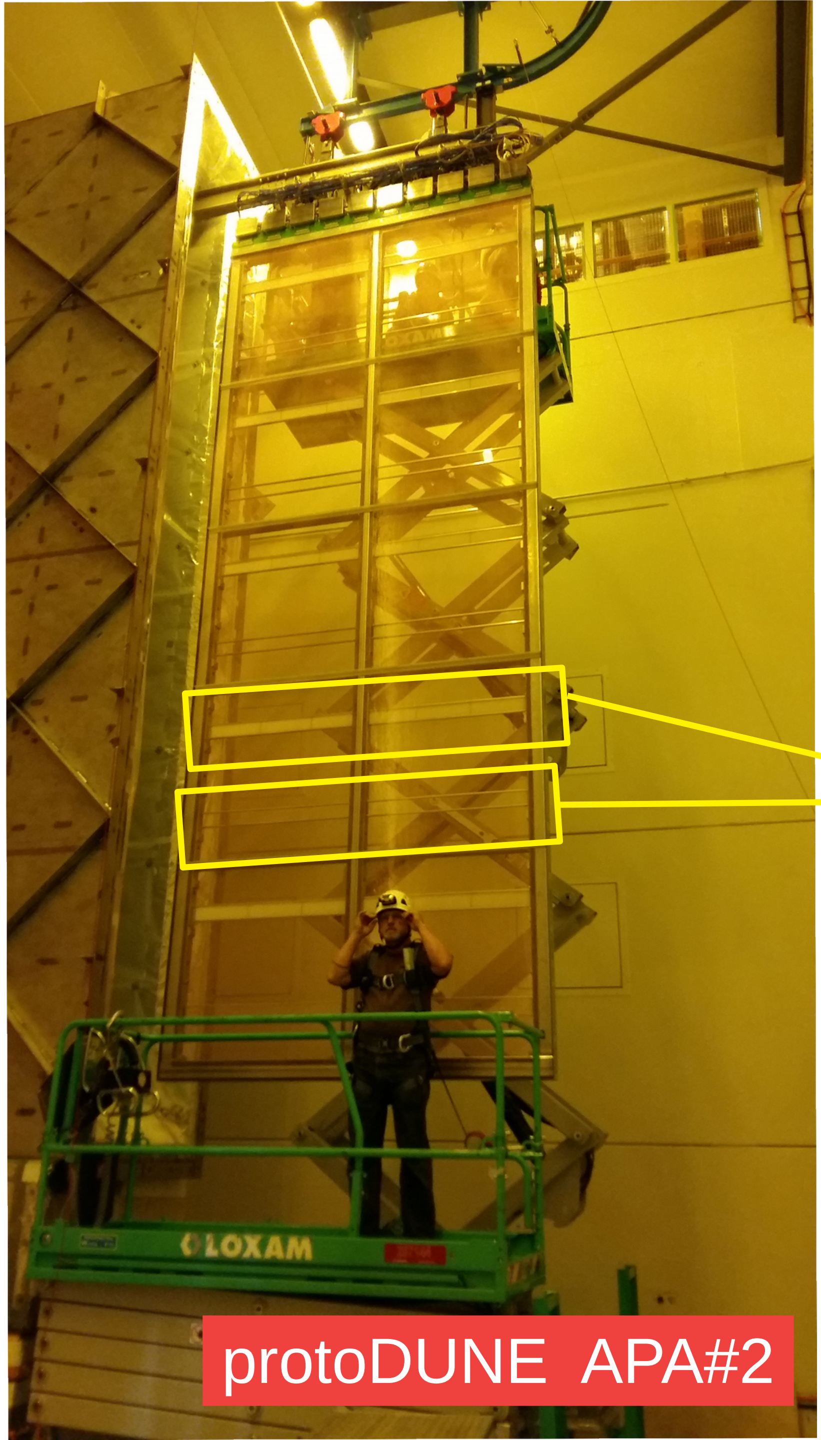
SP PD Scope

The scope of the photon detector (PD) system for the DUNE far detector reference design includes design, procurement, fabrication, testing, delivery and installation of the following components:

- ***Light collection system***. **Three alternative designs at the moment**
  - ✓ ***Two different flavors of shifting/guiding bars*** (*Double-shift bars and dip-coated bars*) → Technologies under development for several years. Quite robust and mature technologies. ***Quantum efficiencies at the level of 0.1% – 0.3%***
  - ✓ **ARAPUCA** . A new concept of light trap. New technology proposed 2 years ago. Possibility of reaching ***Quantum efficiencies at the few percent level***. ***Measured prototype QE at the level of 0.4% - 1.8%.*** Needs development.
- ***Silicon photomultipliers (SiPMs)***
  - ✓ SensL SiPM used in early prototypes and installed in protoDUNE not reliable at cryogenic temperatures due to a change in the packaging (Summer 2016). Alternatives are needed.
  - ✓ **Developing Cryogenic SiPM with Hamamatsu**. Collaboration with **FBK** (Fondazione Bruno Kessler, Italy). **Contacts with DarkSide Collaboration.**
- ***Readout electronics***
  - ✓ **Most expensive subsystem of PD**. Exploring low cost alternatives to waveform high frequency digitization. *The need of pulse shape discrimination of the signal is being deeply investigated within Physics and Simulation WG.*

- ***Related infrastructure (***APA mounting, cabling, cryostat flanges, etc.)



The final design for the SPPD will be very close to the protoDUNE one:

Bar shaped PD modules slided inside the APA frame between wire planes

Read-out by SiPM

- **29 Double-shift guiding bars**
- **29 Dip-coated guiding bars**
- **2 ARAPUCA modules**

Two different styles of light guides

First ARAPUCA module installed in APA#3

Requirements

DUNE-doc-112-v17 FD-sci-eng-requirements

	heading		Photon Detection				
FD-pds-001	requirement	glo-sci-27, 34	Photon sytem performance I	The far detector photon system shall detect sufficient light from events depositing visible energy >200 MeV to efficiently measure the time and total intensity.	This is the region for nucleaon decay, atmopheric neutrinos. The time measurment is needed for vertex determination as specified in the parent. We require that this effiency be high since this is high priority physics.	If proton decay vertex in the fiducial cannot be determined well , then the sensitivity will be affected by backgrounds from cosmic ray muons.	
FD-pds-002	requirement	glo-sci-28, 34	Photon System perfromance II	The far detector photon system shall detect sufficient light from events depositing visible energy <200 MeV to provide a time measurement. The efficiency of this meansurement shall be adequate for supernova burst events.	This points back to low energy measurement of vertex for supernova burst events. Since the trigger is based on burst, the background is expected to be small, and so the main rationale behind this measurment is to improve the energy resolution.	Efficiency could vary significantly from visible energy of 5 MeV to 100 MeV.	
FD-pds-003	requirement	glo-sci-8	Photon system readout electronics	The far detector photon system readout electronics shall record waveforms continuously with sufficient precision and range to achieve the key physics parameters.	The resolution and dynamic range needs to be adjusted so that a few photo-electron signal can be detected with low noise. The dynamic range needs to be sufficiently high to measure light from a muon traversing a TPC module.	The current design readout will output time and pulse height continuously. Need to be able to synchonize with the TPC.	

- The far detector photon system shall detect sufficient light from events depositing **visible energy >200 MeV** to efficiently measure the *time and total intensity.*

- The far detector photon system shall detect sufficient light from events depositing **visible energy <200 MeV** to provide *a time measurement*. The efficiency of this measurement shall be adequate for **supernova burst events**.

- The far detector photon system readout electronics shall record waveforms continuously with sufficient precision and range to achieve the key physics parameters.

Requirements cont.

These requirements have been translated into detector performance requirements:

- ***Minimum Light Yield of 0.1 pe/MeV at the Cathode Plane Assembly*** – farthest point from PD modules
- ***Time resolution of 1 μsec*** → not an issue for currently prototyped PD modules and electronics
- ***Requirements elaborated few years ago without the support of a reliable Monte Carlo simulation of light production/propagation/detction****. Huge efforts are being made inside the Consortium and a* ***complete simulation is expected by fall 2018***
- Our current understanding is that these requirements ensure a ***detection efficiency of light signal > 90% for energy deposit > 200 MeV*** and around ***50% for SN events*** (*integrated over a nominal SN spectrum and requiring flashes to be matched to the original event*)
- The translation of this detector performance into quantum efficiencies of photon detector modules is not solid for the same reason. ***Actual estimates are around 0.5%***
- **Improving MC simulation is a key point and is a priority of the Consortium.** Fundamental to estimate detector performance in function of LY and for translating it into detector performance.

Key Consortia Interfaces

The photon detector consortium has generated interface control documents with all other relevant consortia. Some critical interfaces include:

- ***APA Consortium***
  - Number and dimensions of PD insertion slots
  - PD support frame components
  - Cable routing space
  - Grounding scheme

- ***CPA Consortium***
  - Calibration system mounting
  - Possible WLS/light reflector foils

- ***Cold Electronics Consortium***
  - Signal interference
  - Cryostat flanges
  - Cable routing

- ***Infrastructure group***
  - PD installation and checkout tooling
  - Environmental conditions required post PD installation
  - Cryostat installation/cabling requirements

Strategy

- **Physics and Simulation, Computing**

Continuing refinement of our understanding of performance requirements of the PD system is critical to guide our development efforts.

  - ***Solicit input from the DUNE Physics*** team to better define the ***required performance*** for desired physics measurements in DUNE
  - Develop a ***matrix detailing the detector performance requirements*** for the desired physics measurements
  - Define the required performance and readout requirements for the ***PD electronics*** (e.g. *full waveforms vs. integrated charge, triggering, etc*.) to try to minimize cost and data rate.

- **Photosensors**

SiPM selection, evaluation, and cryogenic certification are a crucial development focus. ***Consortium is collaborating with Hamamatsu and FBK in developing cryogenic SiPMs***. Contacts with ***DarkSide Experiment for a possible collaboration on photosensors*** (and electronics). R&D into ***SiPM ganging*** (both active and passive) *to reduce channel count* represents a prime opportunity for project cost savings which must be aggressively pursued.

Strategy cont.

- **Light Collection**
  - *Current bar designs do not meet (or marginally meet) the minimal requirements of LY. Light read-out at both ends of the bars and better matching of SiPM spectral sensitivity spectrum (more difficult) could increase the efficiency by more then a factor 2, which should allow to match the minimal requirements.*
  - **Increasing the detection efficiency** of the collectors is a priority of the Consortium to match the minimal requirements in a robust and solid way in order to be **insensitive to inaccuracies of Monte Carlo simulations** and to **performance degradation of the system during the operation of the far detector** (*dead channels*, *decrease of SiPM efficiencies*, *decrease of wavelength shifting efficiency* – never tested on a ten/twenty years scale!
  - ***The ARAPUCA design has the potential to provide a significantly higher LY than the solid bars; this option is being investigated intensely to demonstrate sufficient maturity prior to the TDR***. Other light enhancement systems such as wave-shifting *foils on the cathode planes and increasing the area of PD modules* (modification to APA design needed - only modest changes, that do not require significant re-engineering) will be investigated.

- **Electronics and Cabling**
  - **Readout electronics represent a very significant fraction of the PD system cost**. Great effort is ongoing to understand ***the requirements on the signals and in particular to understand the need of having access to the digitized waveform sampled at the nanosecond level*** to perform *pulse shape discrimination (PSD) with light*. At the moment no strong physics case in favor of PSD. *Much cheaper alternatives can be considered* - ***signal integration and much slower digitization at the 100 nanosecond level or more.***

Testing and Decision Strategy

By the mid-2018, the Photon Detector consortium will establish light collection efficiency and detector performance requirements to meet the physics goals of DUNE.

Prior to the TDR, the following decisions will have been reached:

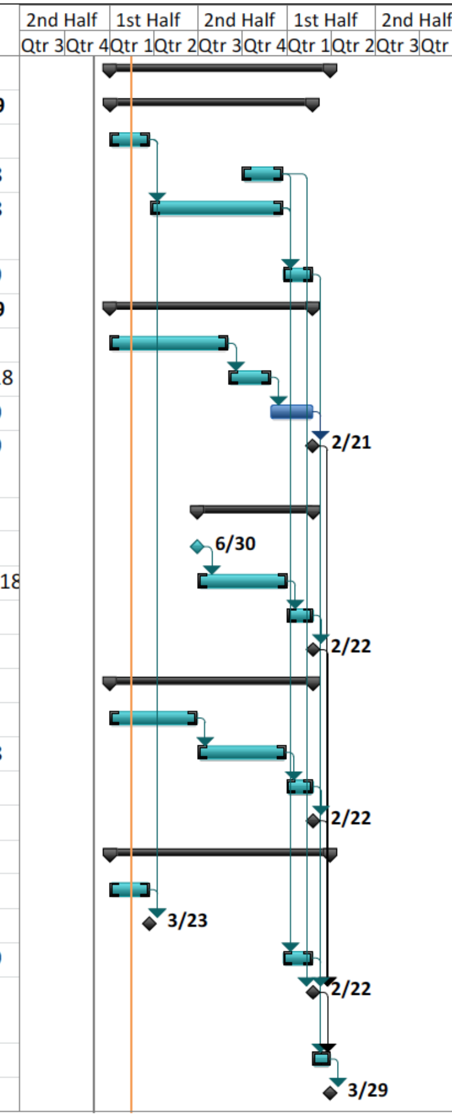
- ***Select a baseline and possibly one alternate light collector technology for use in the first 10 kt SP far detector.*** The results necessary for this comparison between the two bar-based technologies will come primarily from **ProtoDUNE,** supplemented by *additional testing in other facilities as needed.* **More novel light collection schemes may require significant additional testing at other facilities** (ARAPUCA prototypes deployed in ProtoDUNE represent a very early version of the technology)

- ***A single candidate photosensor will have been selected*** and have gone through preliminary *long-duration aging studies*. Additionally, ganging studies, including cold pre-amplification tests, will have been conducted and evaluated, and a single photosensor mounting scheme settled on.

- ***Readout electronics will have been tested to read out PD modules of the baseline technology,*** and perhaps one *alternate*, while mounted in an operational APA frame in concert with cold electronics. These tests may occur at the **Cold Box at CERN**, in **Tallbo**, or in the large-scale cryostat at Fermilab

Schedule

ID	WBS	Task Name	Duration	Start	Finish
205	**9**	**Single Phase Photon Detector**	**325 days**	**Mon 1/1/18**	**Fri 3/29/19**
206	**9.1**	**Physics/Simulation**	**298 days**	**Tue 1/2/18**	**Thu 2/21/19**
207	9.1.1	Preliminary assessment of Physics requirements for Photon Detection system	59 days	Tue 1/2/18	Fri 3/23/18
208	9.1.2	Quantify performance of PD Options in ProtoDUNE	60 days	Mon 10/1/18	Fri 12/21/18
209	9.1.3	Run simulations studies to better quantify physics requirements for Photon Detection	195 days	Mon 3/26/18	Fri 12/21/18
210	9.1.4	Quantify performance of DUNE PD options with respect to physics requirements	44 days	Mon 12/24/18	Thu 2/21/19
211	**9.2**	**Light Collectors**	**299 days**	**Mon 1/1/18**	**Thu 2/21/19**
212	9.2.1	Development of next generation ARAPUCA technology	175 days	Mon 1/1/18	Fri 8/31/18
213	9.2.2	Testing of next generation ARAPUCA design	62 days	Mon 9/3/18	Tue 11/27/18
214	9.2.3	Analysis of next generation ARAPUCA test data	62 days	Wed 11/28/18	Thu 2/21/19
215	9.2.4	Results of performance studies of advanced prototype testing and technology comparison	0 days	Thu 2/21/19	Thu 2/21/19
216	**9.3**	**Photosensors**	**170 days**	**Sat 6/30/18**	**Fri 2/22/19**
217	9.3.1	Sample-lots of candidate photosensors in hand, along with testing facilities	0 days	Sat 6/30/18	Sat 6/30/18
218	9.3.2	Testing of candidate photosensors and photosensor ganging	131 days	Mon 7/2/18	Mon 12/31/18
219	9.3.3	Analysis of photosensor test data	39 days	Tue 1/1/19	Fri 2/22/19
220	9.3.4	Results of evaluation and availability of integrated photosensor-electronics	0 days	Fri 2/22/19	Fri 2/22/19
221	**9.4**	**Electronics/Cabling**	**300 days**	**Mon 1/1/18**	**Fri 2/22/19**
222	9.4.1	Development of optimized electronics readout and cabling design	130 days	Mon 1/1/18	Fri 6/29/18
223	9.4.2	Prototyping and testing of optimized electronics readout and cabling	130 days	Mon 7/2/18	Fri 12/28/18
224	9.4.3	Analysis of optimized electronics test data	40 days	Mon 12/31/18	Fri 2/22/19
225	9.4.4	Results of evaluation of optimized electronics	0 days	Fri 2/22/19	Fri 2/22/19
226	**9.5**	**TP/TDR**	**324 days**	**Tue 1/2/18**	**Fri 3/29/19**
227	9.5.1	Establish preliminary criteria for PD technology down-select (included in TP)	59 days	Tue 1/2/18	Fri 3/23/18
228	9.5.2	SP-Photon Detector Technical Proposal - Submit for Internal Review	0 days	Fri 3/23/18	Fri 3/23/18
229	9.5.3	Establish final criteria for PD technology down-select	44 days	Mon 12/24/18	Thu 2/21/19
230	9.5.4	Down select to primary (and alternate if required) technologies for all Photon Detector components	0 days	Fri 2/22/19	Fri 2/22/19
231	9.5.5	Final editing of TDR	26 days	Fri 2/22/19	Fri 3/29/19
232	9.5.6	SP-Photon Detector TDR - Submit for Internal Review	0 days	Fri 3/29/19	Fri 3/29/19



Project: FD Int schedule
Date: Fri 2/16/18

Task		External Milestone		Manual Summary Rollup	
Split		Inactive Task		Manual Summary	
Milestone		Inactive Milestone		Start-only	
Summary		Inactive Summary		Finish-only	
Project Summary		Manual Task		Deadline	
External Tasks		Duration-only		Progress	

Key Milestones

Photosensors:

- **End of Q2 2018**: Sample-lots of candidate photosensors in hand, along with testing facilities.
- **End of Q4 2018**: Testing results from candidate photosensors and photosensor ganging (cold pre-amplification and passive ganging).

Light Collectors:

- **End of Q3 2018**: Criteria and procedure defined for down select between Light Collector technologies.
- **End Q4 2018**: Analysis of initial PD performance results from ProtoDUNE operation, including comparison between candidate designs.
- **End Q4 2018**: Results of performance studies of ARAPUCA prototype testing and technology comparison (other than ProtoDUNE)

Electronics/Cabling:

- **End of Q4 2018**: Testing results from candidate alternative electronics readout and cabling plan.

Risks and mitigation

- **PD Modules don't collect enough light to meet system physics performance requirements**

Allocate enough development resources to the PD to continue developing improved light collection modules. Increase the APA slot size to allow for larger modules. Increase the number of modules per APA.

- **Cabling for PD and CE can not be accommodated within the 2-APA assembly/installation procedure.**

Explore other options for cable routing, to attempt to avoid routing the PD and CE cables in the same space. Particularly consider routing the PD cables outside the APA side tubes, inside the frame.

- **SiPMs windows fail due to multiple cold cycles/extended cryogenic exposure**

Develop alternate vendors and require performance certification from vendors. Continue testing of candidate SiPMs to insure acceptable performance. Develop QC procedures to catch failed devices prior to FD installation

- **SiPM active ganging required to minimize electronics costs**

Continue development of active ganging circuits and investigate in Tallbo and other non-ProtoDUNE test beds.

- **PD/CE Electrical Crosstalk**

Test combined readout systems in FNAL CE test bed as soon as possible. Build full-scale mechanical prototype of cable runs as soon in the development process as possible.